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ABSTRACT

This document concerns recommendations for the chemistry content needed for preservice science teachers as determined by the American Chemical Society (ACS). Topics include: (1) process description; (2) relationship to National Science Education Standards; (3) recommendations for content; and (4) contributors to the project. (KHR)

Recommendations for Content

from the

American Chemical Society

for the subject of

Chemistry

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Section I. Process Description.

The American Chemical Society, through its Society Committee on Education (SOCED), appointed a team to develop the recommendations for the preparation of chemistry teachers. SOCED appointed George Palladino, chair of the SOCED Subcommittee on Pre-college Education, to be the chair of the Science Teacher Preparation (STP) team. Michael Tinnesand, Assistant Director for K-12 Science in the Education and International Activities Division, was staff liaison for the team. SOCED directed that the team include representatives that included high school teachers, college faculty, and the members of the ACS Committee on Professional Training (CPT). The team consisted of the following members.

Connie Blasie, University of Pennsylvania, Philadelphia, PA
Kathryn Scantlebury, University of Delaware, Newark, DE
Pernell Williams, Edison Schools, Washington, DC
Pam Abbott, Roxana High School, Bethalto, IL
Joe Heppert, University of Kansas, Lawrence, KS
Margaret Merritt, Wellesley College, Center Sandwich, NH
Barb Sitzman, Chatsworth High School, Tarzana, CA

The team spent June and July independently studying background documents, including the existing NSTA standards, the National Science Education Standards (NSES), the AAAS Benchmarks for Science Literacy, the NRC report on the preparation of Advanced Placement Teachers, and other relevant reports.

The team met in Washington, DC, at the ACS headquarters building July 20-21, 2002.The team spent one and a half days considering the recommendations for the NSTA standards.

The draft document was reviewed and edited at the ACS National Meeting in Boston, MA, August 15, 2002, by Subcommittee A of the Society Committee on Education (SOCED).

Section II. Relationship to National Science Education Standards.

The ACS/STP team reviewed and incorporated the recommendations for teacher preparation from the National Science Education Standards, the AAAS Benchmarks, and also the Core Curriculum suggestions for ACS Approved Degree Programs. CPT was in the process of revising their own standards for a chemical education specialty approval and these draft standards were also reviewed.

Section III. Recommendations for Content.

A. <u>Recommendations for Elementary Generalists</u>.

Elementary science generalists, who should have basic knowledge across sciences, in this discipline should know and understand:

- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Some of those properties are extrinsic and others are intrinsic.
- Properties can be measured using tools, such as rulers, balances, and thermometers.

Measurements have error and uncertainty associated with them.

- Objects are made of one or more materials, such as pure substances or mixtures. Objects can be described by the properties of the materials from which they are made, and those properties can be used to separate or sort a group of objects or materials.

- Materials exist in different physical states--solid, liquid, and gas—and the conditions necessary for common materials such as water to be changed from one state to another.

- A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.

- Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties. In chemical reactions, the total mass is conserved.

- Materials are composed of parts too small to see. These parts are called atoms. Atoms are composed of subatomic particles.

- Energy is associated with transformations of matter and energy is transferred in many ways. Among the forms energy can take are heat, light, electricity.

- How to use level appropriate mathematics as a tool in the analysis of data.

Rationale: Teachers need the ability to present science as an experimental endeavor. Their students should be engaged in hands-on experimentation in science early in their learning. In order to guide this process, teachers must have the basic "tools" for doing science.

The recommendations listed above are based on the National Science Education Standards and the AAAS Benchmarks for Science Literacy. One variance is that we encourage teachers to understand the particulate nature of matter and the atomic theory as foundational information for themselves. However, we support the idea as put forth in the NSES that information about the particulate nature of matter not to be a part of student instruction. The purpose of this background knowledge is to help bolster the confidence of elementary teachers to present science to their students. It is essential that the content information be presented to elementary teachers in a way similar to how they should teach their own students. Chemistry should be learned as a series of interconnected concepts. It would be most helpful if teachers learned chemistry in the context of well-designed, integrated, inquiry-based courses.

B. <u>Recommendations for Elementary Specialists and Middle-Level Generalists</u>.

The elementary science specialist, or the middle level generalist with a science specialization (under National Middle School Association Standards) should in this discipline know and understand:

- Chemical elements do not break down during normal laboratory reactions involving such treatments as heating, exposure to electric current, or reaction with acids or bases. There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances that we encounter.

- Substances often are placed in categories or groups if they react in similar ways or have similar chemical behavior.

- Heat energy flows from warmer objects to cooler ones, until both reach the same temperature.

- In most chemical reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers. Matter and energy are conserved in these reactions.

- The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting radiation. A tiny fraction of that radiation reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as radiation with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

- Water is an example of a substance that dissolves many materials to form solutions. These solutions are important in many processes such as water cycle and groundwater purity.

- The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth can move among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of biogeochemical cycles.

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The attractive force between the nucleus and electrons holds the atom together.

- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. A small, dense nucleus is surrounded by a diffuse cloud of electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.

- Bonds between atoms are created when electrons are paired by being transferred or shared. A substance composed of a single kind of atom is called an element. The

atoms may be bonded together into individual molecules or crystalline solids. A compound is formed when two or more kinds of atoms bond.

- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.
- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
- Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light and other forms of radiation can initiate many chemical reactions such as photosynthesis and the formation of urban smog.
- Atoms and molecules are in constant motion. In solids they form a structure that is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart relative to their size.
- An increase in temperature reflects an increase in molecular motion.

Rationale: The ACS team recommendations listed above are based on the National Science Education Standards and the AAAS Benchmarks for Science Literacy. Many different teaching assignments are covered by these recommendations. Middle-school generalists may be full-time science teachers. Elementary specialists may teach science in support of a number of elementary teachers, be supervising mentors for other teaching peers in their building or district, or be a self-contained classroom teacher with a love of science. Elementary specialists and middle-school generalists should understand and be able to present the core ideas of chemistry listed above as an overarching conceptual background for their teaching. Some teachers may require additional specialized content knowledge depending on their individual classroom assignments. Selected foundational materials above the levels expected for student learning are listed. It is extremely important for pre-service and in-service teachers to gain a conceptual understanding of the chemistry core content and its application to the real world, not just the learn a set of unconnected facts. Teachers must be able to present material in a manner that allows students to understand the connectivity of broader concepts and not just sets of discrete facts. The AAAS Project 2061 *Atlas of Science Literacy*, based on the AAAS Science For All Americans study, contains strand maps entitled *Atoms and Molecules, Conservation of Matter, States of Matter, Chemical Reactions, and Interactions Between Energy and Matter* that utilize benchmarks to illustrate a progression of ideas and skills arranged by grade-level areas.

Since we tend to emulate methods we have learned, the basic college preparation program for these teachers should contain science content classes that utilize an abundance of collaborative group work and hands-on laboratory experiences — especially in the area of inquiry. Pre-service teachers should be instructed in interdisciplinary science approaches and understand that varied presentation methods are

necessary to address the numerous types of student learners in today's classrooms. In-service teachers who realize that teachers should be life-long learners will continue their professional development to refine their skills in the chemistry content areas and to keep abreast of the changing pedagogy in our field.

C. Recommendations for Secondary Science Teachers.

1. Core Knowledge: All candidates teaching in this discipline should know and understand:

Chemical Bonding

- Fundamental aspects of bonding and structure, in organic compounds, including, valence bond concepts, isomerism (i.e., constitutional and stereo), electronegativity, electron delocalization.
- Intermolecular forces, including electrostatic interactions, dipole-dipole, and hydrogen bonding.
- Ionic substances, lattice and close packing concepts; ionic radii.
- Covalent molecular substances, geometries, Lewis structures, VSEPR concepts, valence bond theory (hybridization, sigma, and pi bonds), electronegativities, bond energies, and bond length.
- Metallic substances, metallic bonding, conductivity, semiconductors, insulators, superconductors, metallurgy (occurrence, recovery, refining, reactivities) alloys and other "metallic" substances.

Dynamics-Interaction of Matter and Energy

- Chemical kinetics, including a brief introduction to rate laws, collision theory, catalysis, the relationships between thermodynamics and kinetics and the application of kinetics to mechanisms.
- Thermodynamics and equilibria, standard functions (enthalpy, entropy, Gibbs, etc.) and applications. Microscopic point of view especially for entropy. Gibbs chemical potential applied to chemical and phase equilibria.
- Quantitation of equilibrium and kinetic aspects of chemistry
- Thermodynamics of electrochemical cells.
- Kinetics and mechanisms of biological catalysis

Structure and Property of Matter

- Atomic structure, spectra and orbitals, ionization energy, electron affinity, shielding and effective nuclear charge.

- Main group elements, distribution, occurrence, isolation, recovery, structures, properties; synthesis, structure, physical properties, acid-base character, and reactivities of their compounds; periodic trends, e.g., metallic character of the elements, bond strengths and energies.
- Mole concept, including stoichiometry and laws of definite and multiple composition.
- Transition elements and coordination compounds, ligands, coordination number, stereochemistry, and nomenclature; descriptive chemistry (synthesis, structures, properties, acidities, reactivities, electrochemistry, magnetic properties), bonding and spectroscopy.
- Fundamental biochemical building blocks (amino acids, carbohydrates, lipids nucleotides, and prosthetic groups), biological membranes, Macromolecular conformations

Reactivity and Applications

- Correlation of chemical reactivity and molecular structure.
- Acids and bases, acidic, basic, and amphoteric substances; buffers, Bronsted-Lowry, Lewis definitions.
- Oxidation and reduction chemistry including electrochemistry (galvanic vs. electrolytic cells), electroplating, corrosion, and refining of ores.
- Isolation and purification techniques, including extraction, distillation, sublimation, crystallization, and various forms of chromatography.
- Solutions, properties of solutions and colligative properties.
- Functional group chemistry, including the preparation, reactions, and nomenclature of the major classes of organic compounds including polymers and biopolymers.
- Laboratory synthesis including the synthesis of an appropriately selected group of simple compounds.
- Polyfunctional substances, including the major classes of biological compounds and natural products, including the major classes of biological compounds, natural products, enzymes, metalloenzymes, and nucleic acids.
- Environmental and atmospheric chemistry including, groundwater and air quality, origin and effects of acid rain, global temperature change, geologic origin of minerals, and stratospheric ozone levels.

General Chemical Skills and Knowledge

- Chemical and lab safety, including chemical storage and disposal of wastes.

- Lab skills and techniques typically required for the synthesis and characterization of compounds and the study of chemical reactions and processes. Comparison and critical selection of methods for elemental and molecular analyses The distinction between qualitative and quantitative goals of determinations
- Sampling methods for all states of matter. Statistical methods for evaluating and interpreting data. Computer-based data acquisition systems for analytical instruments. Concept of instrument calibration
- Sources of error in chemical and instrumental analysis. Standardization methodology
- Concepts of validation of data and experimental design
- Library and communication techniques, including bibliographic instruction in manual and electronic methods and experience with written reports and keeping a laboratory notebook.
- Process of science especially how research is done.

Rationale: Our recommendations are based on the ACS CPT's *Guidelines for Preparation in Chemistry* and the draft CPT *Suggestions for the ACS Chemistry Education Option*. CPT is charged with developing and administering guidelines for the ACS approval of post-secondary chemistry programs.

We emphasize teaching to the NSES Physical Science Standards: Structure of Atoms, Structure and Properties of Matter, Chemical Reactions, Conservation of Energy and Increase in Disorder, and Interactions of Energy and Matter. Secondary teacher training should include at least 200 hours of laboratory experience in chemistry including experimental design, research, and open-ended investigations. We consider this minimum set of standards a sufficient foundation for teachers to implement NSES Standards-based teaching. As their careers proceed, teachers can build on their understanding of basic concepts to increase their ability to challenge students and to prepare for teaching advanced high school chemistry courses. Inservice and other forms of professional development should relate directly to their teaching situation, and be an integral part of their professional practice, thus encouraging life-long learning and collaboration with other professionals.

The lab experience is critical and should include inquiry based lab experiences, experimental design, control of variables, communication of results, team and independent research, computer assisted collection and analysis of data, report writing and error analysis, development of models, relevance to 'real-world'.

Although the lists presented for these standards are presented as individual items for clarity, it is important to note that we do not suggest that the study of chemistry should be presented as a set of factoids to be memorized. Not every teacher needs to know every fact. They need to know the big ideas and principles and beyond that, they need to know how to find answers they don't know already.

2. All candidates teaching in this discipline should know and understand the following from the other sciences:

- Ability to use mathematics as a tool in the design and execution of experiments, analysis of data and in modeling chemical processes.

- Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.

- Atoms and molecules on the earth cycle among the living and nonliving components of the biosphere.

- Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers.

- Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors are threatening current global stability, and if not addressed, ecosystems will be irreversibly affected.

- All matter tends toward more disorganized states. Living systems require a continuous input of energy to maintain their chemical and physical organizations. With death, and the cessation of energy input, living systems rapidly disintegrate.

- Energy for life primarily derives from the sun. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing (organic) molecules. These molecules can be used to assemble larger molecules with biological activity (including proteins, DNA, sugars, and fats). In addition, the energy stored in bonds between the atoms (chemical energy) can be used as sources of energy for life processes.

- Cells usually store energy derived from the metabolism of food temporarily in phosphate bonds of a small high-energy compound called ATP.

- As matter and energy flows through different levels of organization of living systems--cells, organs, organisms, communities--and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment. Matter and energy are conserved in each change.

- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

- Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.

Rationale: People with a strong conceptual understanding of chemistry are able to use their knowledge to develop interdisciplinary approaches to science teaching. This understanding of chemistry will form the basis for connecting with biological and physical concepts. When teachers learn to make connections, scientific facts will not be taught in isolation and students will learn to distinguish between major concepts and facts. Students, including those in teacher preparation programs, learn when they are actively involved in their education through opportunities to collaborate, participate in class discussions, and design laboratory investigations. Inquiry-based, real-world investigations lead to the discovery of connections between chemistry and other science disciplines, and the application of these connections to problem solving. The importance of using mathematics, statistics, modeling, and computer applications to explain daily phenomena should be emphasized.

Chemistry departments must recognize their obligation to create interesting core courses for <u>all</u> students, including those who are not chemistry majors, and to recognize that a basic understanding of the role of chemistry in our daily lives is important for future citizens and community leaders. We suggest that all core courses should include historical perspectives, current developments, and relevant demonstrations of materials chemistry, polymer chemistry, and applied chemistry. Attention should also be given to chemical safety, the systematic use of chemical literature, and computer applications.

3. Advanced Knowledge: All teachers for whom this science is their major or primary teaching field should know and understand:

Chemical Bonding

- Molecular orbital theory, aromaticity.

- Ionic substances, lattice energy calculations and correlation to properties (solubility, hardness, etc.).

- Metallic substances, close packing concepts.

Dynamics-Interaction of Matter and Energy

- Chemical kinetics, elucidation of organic reaction mechanisms.

- Kinetic Theory, Maxwell-Boltzmann distribution, collision frequency; effusion rate. Equipartition of energy; heat capacity. Transport processes.

- Kinetics, differential and integral expressions with emphasis on multistep as well as single-step first-order phenomena. Relaxation processes. Microscopic reversibility. Expressing mechanisms in rate laws. Steady state approximation. Collision theory. Absolute rate theory.
- Thermodynamics and non-ideal systems; standard states; activities; Debye-Huckel limiting law. Gibbs phase rule; phase equilibria; phase diagrams.

Structure and Property of Matter

- Lewis adducts and coordination compounds; organo derivatives, simple anions, oxoacids and their salts.
- Major classes of biological compounds and natural products, including enzymes, metalloenzymes, and nucleic acids. Biopolymers (nucleic acids, peptides/proteins, glycoproteins, and polysaccharides)
- Solutions and colligative properties.

Reactivity and Applications

- Solvent system concepts; non-aqueous solvents.
- Correlation of chemical reactivity and molecular structure, including the influences of electronic and steric effects in the gas phase and in solution.
- Organic synthesis, including multi-step syntheses with an introduction of retrosynthetic planning, the application of modern synthetic methods including organometallic reagents, and the use of protecting group strategies.
- Reaction mechanisms, including nucleophilic and electrophilic substitution, addition and elimination reactions, free radical reactions, cycloaddition reactions, molecular rearrangements, photochemical reactions, oxidation and reduction reactions, and metal mediated reactions.

General Chemical Skills and Knowledge

- Principles of green chemistry
- Concepts of availability and evaluation of analytical standards Interferences in chemical and instrumental analysis
- Spectroscopic techniques, including hands-on use of UV/Vis, IR, NMR, and mass spectroscopy for the identification of appropriately chosen "unknown" compounds.
- The principles of and instrumentation for atomic, molecular, and mass spectrometry, magnetic resonance spectrometry, chromatography and other methods of separation, electroanalytical methods, and thermal methods

Rationale: Our recommendations are based on the CPT requirements for an approved bachelors degree in chemistry and the NSES Physical Science Standards: Structure of Atoms, Structure and Properties of Matter, Chemical Reactions, Conservation of Energy and Increase in Disorder, and Interactions of Energy and Matter. These guidelines build on and extend the core curriculum (see Section C.1.). Advanced courses assume core courses as prerequisites. CPT requirements include at least 300 hours of chemistry laboratory experience including an independent research project. In addition to experimental design, students will practice laboratory preparation, stockroom procedures, safety, disposal of chemical waste, and chemical research. The College Board suggests that Advanced Placement teachers have a strong background in chemistry including at minimum a major in chemistry with one year of physical chemistry plus a year of advanced inorganic, and preferably a masters degree in chemistry. Teachers who complete these requirements will have a solid academic background and a deep, conceptual understanding of chemistry. This extensive working knowledge of chemistry will enable them to identify and retrieve knowledge relevant to solving specific problems. They will be prepared to teach advanced courses in a secondary school and serve as chemistry teaching mentors.

We recommend that each chemistry learning experience model pedagogy appropriate for the teaching of chemistry. Core courses which incorporate teaching strategies consistent with modern learning theory provide students with the opportunity to learn chemistry through inquiry, group discussion, collaboration, demonstration, and real-world problem solving. Teachers with a strong background in laboratory procedures feel comfortable in this environment and thus are able to provide a challenging experience for their students. The required independent research project will model the use of inquiry and experimental design in the secondary classroom.

4. All teachers for whom this science is their major or primary teaching field should additionally know and understand the following from the other sciences:

- The content included in one year each of calculus, and physics with lab

Rationale: Although we recognize that the current advanced-level chemistry program is very demanding, well prepared secondary chemistry teachers must understand the relationships between chemistry and other science disciplines. We recommend a minimum of three courses to provide breadth in science. In addition, calculus should be mastered prior to taking physical chemistry and physics. Math applications are particularly important for data analysis and interpretation in research. We recommend that content knowledge be presented in organized, meaningful patterns so that its relevance to current problems or issues is emphasized.

We recommend an individual field or laboratory study in the senior year. While investigating a laboratory-based inquiry problem, students should use a variety of literary research sources, form testable questions, identify controls and variables, use a variety of instrumental and experimental techniques including interactive computer applications, statistically analyze their data, collaborate with peers, and communicate their findings in both written and oral formats. Laboratory research projects involving complex environmental issues require sophisticated experimental designs and the application of

concepts from various scientific disciplines. These projects are designed to enhance student understanding of connections between chemistry and other disciplines.

D. Nature of Science Recommendations.

The following section is a selection of relevant parts of the *Project 2061* work on the nature of science.

THE SCIENTIFIC WORLD VIEW

Scientists share certain basic beliefs and attitudes about what they do and how they view their work. These beliefs, which are listed below, have to do with the nature of the world and what can be learned about it.

- The World Is Understandable
- Scientific Ideas Are Subject to Change
- Scientific Knowledge Is Durable
- Science Cannot Provide Complete Answers to All Questions

SCIENTIFIC INQUIRY

Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypothesis and theories, the kinds of logic used, and much more. The exchange of techniques, information, and concepts goes on all the time among scientists, and there are common understandings among them about what constitutes an investigation that is scientifically valid:

- Science Demands Evidence
- Science Is a Blend of Logic and Imagination
- Science Explains and Predicts
- Scientists Try to Identify and Avoid Bias
- Science Is Not Authoritarian

THE SCIENTIFIC ENTERPRISE

Science as an enterprise has individual, social, and institutional dimensions. These include that:

- Science Is a Complex Social Activity
- Science Is Organized Into Content Disciplines and Is Conducted in Various Institutions
- There Are Generally Accepted Ethical Principles in the Conduct of Science
- Scientists Participate in Public Affairs Both as Specialists and as Citizens

THE NATURE OF CHEMISTRY

Chemical scientists are concerned with changes in matter that are sub-microscopic, changes which result in observable phenomena we see all around us —grass grows, iron nails rust, wood burns. Over time chemical scientists have developed five over-arching

themes: Atoms and Molecules; Conservation of Matter; States of Matter; Chemical Reactivity; and Interactions between Matter and Energy. Teachers should strive to intertwine the significant historical achievements in chemistry in the presentation of the nature of science. They should attempt to present chemistry as a human endeavor, which seeks to improve the knowledge of chemistry and the quality of human life. This is especially important in the presentation of recent technological advances dependent on chemical research.

Some examples that teachers may use are:

Prelude to Chemistry- The works of alchemists in Greece and Persia; the medical and early technological heritage of chemistry, for example the discovery of gunpowder in China and the discovery of chemical electricity.

Boyle's Law

Charles' Law

Dalton's Atomic Theory

Lavoisier's Principle of Conservation of Mass

The Mole and Avogadro's Number

The description of the Atom, including the work of Thomson, Rutherford, and Bohr

The modern description of the Atom (qualitatively) and the work of Schrodinger

Periodic law and the work of Mendeleev and Meyer

Radioactivity

Spectroscopy

The chemical bond (G.N. Lewis, W. Kossel, I. Langmuir, L. Pauling)

Transuranium elements (G. Seaborg and others)

Polymers (H. Staudinger, C. Marvel)

Biochemistry

Structure of DNA (F. H. Crick, J. D. Watson)

Environmental quality through Chemistry

Agricultural Chemistry

Catalysis, including artificial enzyme catalysis

Solar Energy

Superconductors (P. Chu)

Conducting Polymers (A. MacDiarmid)

Health related chemistry, including new drugs, biomimetics, antibiotics, chemotherapy, carcinogenesis

Modern materials such as composites, ceramics, microelectronic devices

Control of chemical reactions-molecular dynamics

Synthesis of natural and unnatural products

Gene structure and RNA splicing

Biotechnology

Modern instrumentation such as molecular beams, synchroton light sources, lasers, NMR

Direct observation of bond making and bond breaking using femtosecond lasers (A. Zewail)

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E. Context of Science Recommendations.

Teachers can provide a context for chemistry as a result of personal experience, knowledge of the history of science or extended projects in which the class engages. Personal experience is always the most important factor in contextualizing science.

Teachers who have participated in chemical research, or who have had positive experiences with chemicals in their lives, can be a powerful resource for students,

assuming that they present these experiences in an objective manner that emphasizes the importance, social context, and personal meaning of chemistry. We strongly favor programs that allow pre-service teachers to participate in an extended (6 to 9 month) research experience in a college or university laboratory or that allow in-service teachers to participate in a research experience or industrial internship during the induction period. NSF has fostered various programs that provide these opportunities, including the Research Experiences for Teachers (RET) program.

Knowledge of both the history of chemistry and the current forefront of the field can foster understanding of how the development of chemistry has been of importance to human society. It can also be a powerful tool for making links to other scientific and technological fields. This may help to increase student engagement with the content. Most modern textbooks used at the college level make explicit links between content topics and significant historical developments throughout the history of chemistry. Among the most prevalent socially relevant issues covered in many texts are the determination of air and water quality, ozone depletion, the development of drug-resistant bacteria, and the conservation of natural resources. Areas of chemistry that reflect current areas of overlap with other sciences and engineering include drug development, the preparation of new types of sensors, the development of more environmentally friendly chemical processes, and the preparation of new materials for the electronics industry and medicine.

Extended projects (i.e. studies based on chemical monitoring of water, soil or the atmosphere, or the investigation of a commercial product) can provide K-12 students with a critical personal context for science. These experiences, in which many different skills and knowledge from diverse sources can be employed, often provide a nucleus around which students can organize accumulated knowledge and experiences. Consequently, the choice of texts, reference materials and resources from the Internet that support group learning, hands on experimentation, and extended student inquiry should assist K-12 students to construct their own context for science.

In addition to numerous resources on the world wide web, the American Chemical Society has developed "Chemistry in the Community", one of the most widely used secondary-level texts that emphasizes hands on laboratory experiences and presents chemistry content in the context of societal issues. Good resources for planning grade appropriate inquiry based learning experiences can be found at the American Chemical Society web site, http://www.acs.org/portal/Chemistry?PID=educatorsandstudents.html, and at the Division of Chemical Education web site, http://divched.chem.wisc.edu/CHED-resources.html.

F. Recommendations with Regard to Other Standards.

The Science Teacher Preparation Standards address the role of content instruction primarily under content Standard 1.0. While we strongly agree with many of the conclusions and recommendations listed under this standard our committee found that sequestering the effects of content instruction under a separate standard was an artificial division of the teacher preparation process. While some programmatic characteristics make this type of approach understandable, we believe that it may increase the difficulty

of fostering the cooperative change in science content courses and teacher education courses that is needed for the systemic improvement of teacher preparation programs.

Instructional and assessment strategies, reflection on the context of science and scientific inquiry, and even choices made in curricula that preservice teachers encounter in college and university science courses have an enormous impact on their perceptions of appropriate practices in these areas at the K-12 level. This suggests that we should move toward an integrated view of how science content instruction and teacher education coursework articulate to prepare teachers who will teach in a manner that embodies the spirit of the National Science Education Standards.

We recommend that NSTA consider drafting future versions of the Teacher preparation Standards that more directly articulate the necessary role of both content and education instruction under each of the ten standards identified in the document. We further suggest that NSTA identify some goals specific to content coursework and education coursework in section X.3 under each standard with the intention that these goals will support the general recommendations outlined under that standard.

Science as inquiry is an important tenet in the preparation of chemistry teachers at all levels. Inquiry may involve the use of chemical materials and equipment and teachers should have a good understanding of the safety issues associated with conducting experiments. The section below provides a brief summary of the safety topics for all teachers.

Safety

ACS and the ACS Board-Council Committee on Chemical Safety publish and provide single copies free of *Chemical Safety for Teachers and Their Supervisors*, and *Safety in the Elementary (K-6) Science Classroom*. These texts address key areas that teachers should know regarding safety in the schools. Teachers at the middle and high school levels should know how to

- safely handle and use hazardous chemicals.
- read and interpret Material Safety Data Sheets (MSDS) for chemicals used or stored in the laboratory.
- be cognizant of OSHA's rules and the implication of those rules for teaching chemistry.
- model good safety practices such as wearing appropriate eye protection, clothing and footwear.
- keep accident/incident records
- maintain a safe working environment in the laboratory and preparation areas
- set-up, organize and maintain a chemical stock room and also the techniques for chemical disposal.
- conduct a safety checklist of their laboratory and preparation areas.

American Chemical Society. (2001). *Chemical Safety For Teachers And Their Supervisors*. ACS: Washington, DC.

American Chemical Society. (2001). *Safety In The Elementary (K-6) Science Classroom.* ACS: Washington, DC.

Technology

Teachers at all levels learn how to use computer resources, including Web page construction. High school teachers should be able to use database & modeling software related to chemistry. Teachers learn how to use grade appropriate technology to enhance student learning.

Section IV. Contributors

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